NAVAL
POSTGRADUATE
SCHOOL

Human Robotic Swarm Interaction Using An Artificial Physics Approach

LT Brenton Campbell

ADVISORS:

Asst Professor Dr. Timothy Chung

Senior Lecturer Richard Harkins

Monterey, California

WWW.NPS.EDU

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
DEC 2014		**00-00-2014 to 00-00-2014**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Human Robotic Swarm Interaction Using An Artificial Physics Approach (Briefing Charts)	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**22**	

What is Artificial Physics?

Artificial Physics (AP)

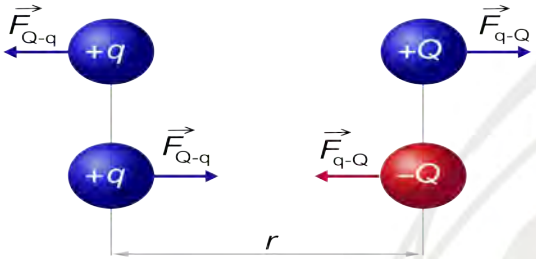
- Based on Newtonian Physics $\vec{F} = m\vec{a}$
- Each agent is treated as a point particle
  - Position x
  - Velocity v
- Discrete time step used to approximate continuous behavior

$$\Delta x = \vec{v}\,\Delta t$$

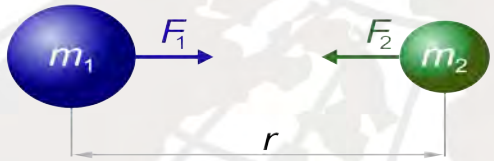
$$\Delta v = \frac{\vec{F}\,\Delta t}{m}$$

Calculated Force

- Modeled after natural forces but not constrained to them
  - Attractive
  - Repulsive

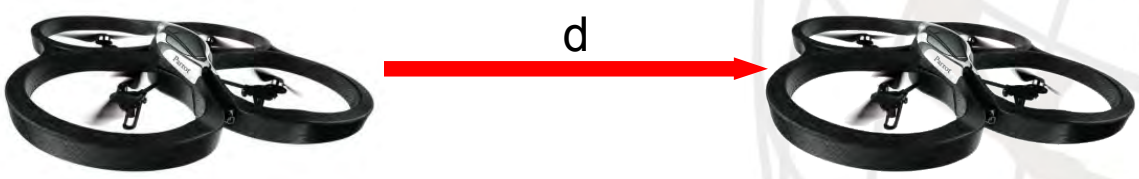


$$|\vec{F}_{Q\text{-}q}| = |\vec{F}_{q\text{-}Q}| = k\frac{|q \times Q|}{r^2}$$

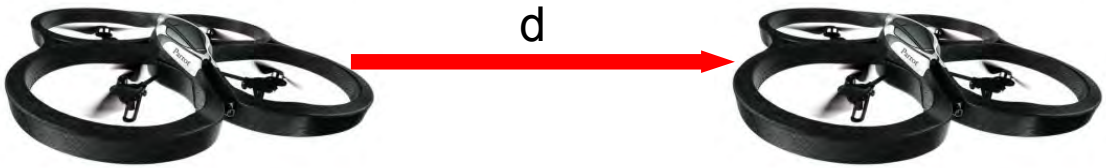


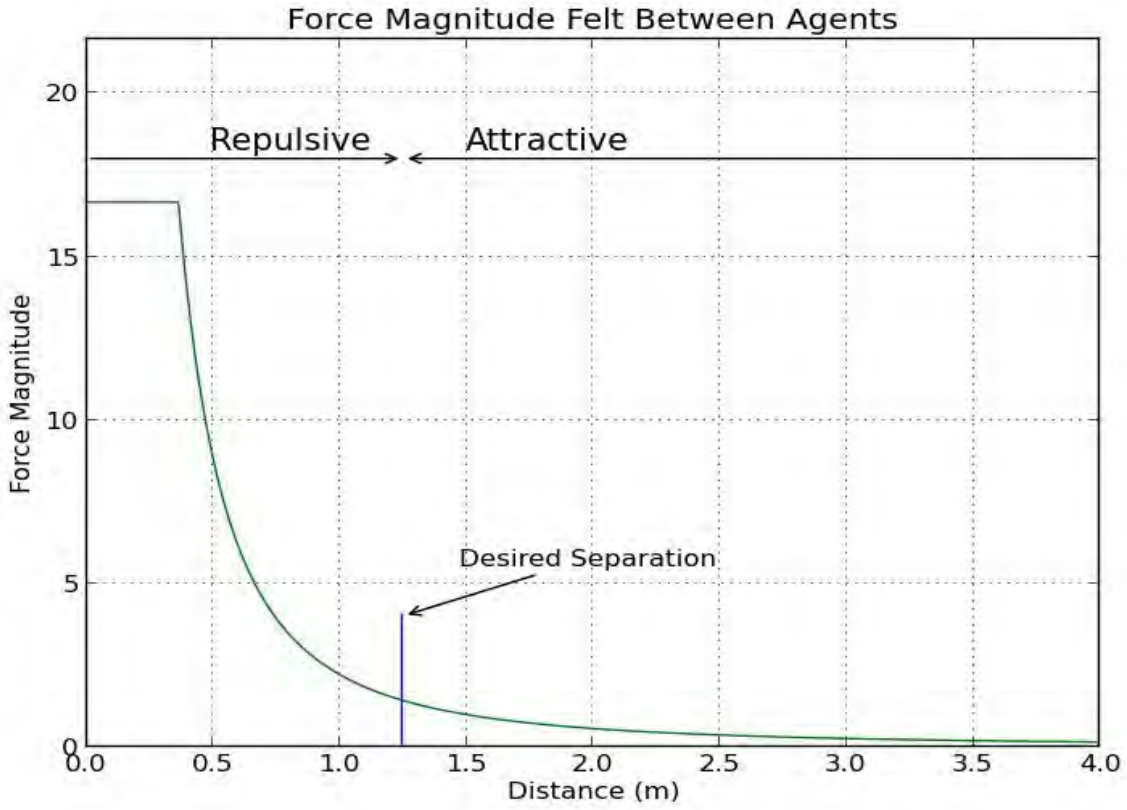
$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

$$\mathbf{F}_{agent} = \frac{GMM}{(d_{m,n})^p}\hat{\mathbf{r}}_{m,n}$$

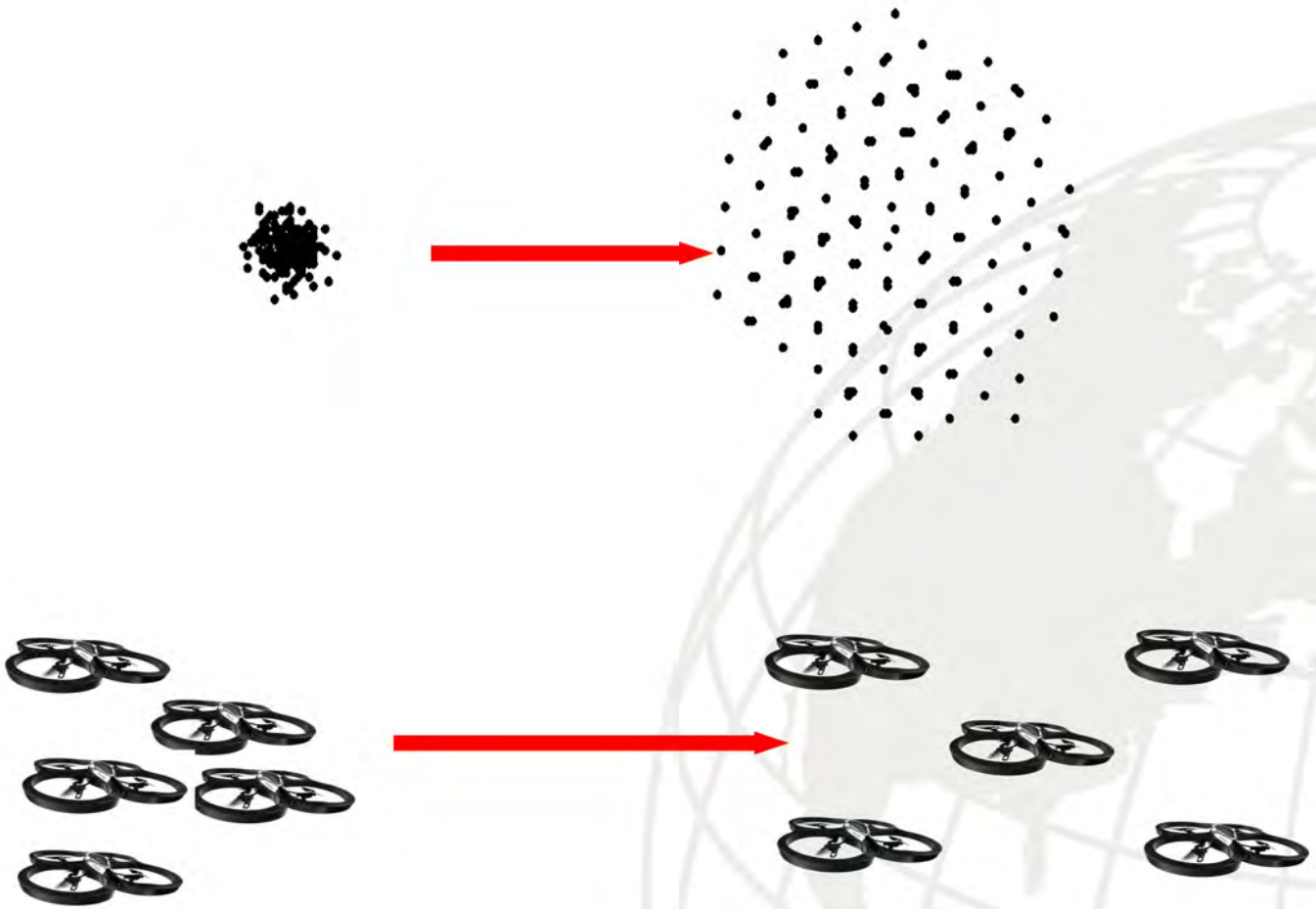


Using AP to Achieve Desired Agent Spacing



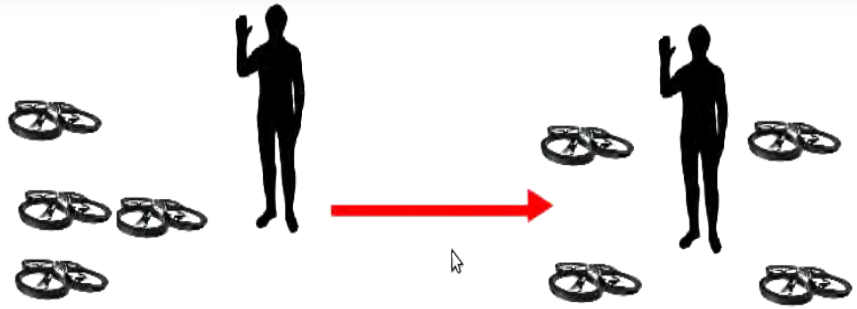


Self Organization into a Lattice



After many Δt

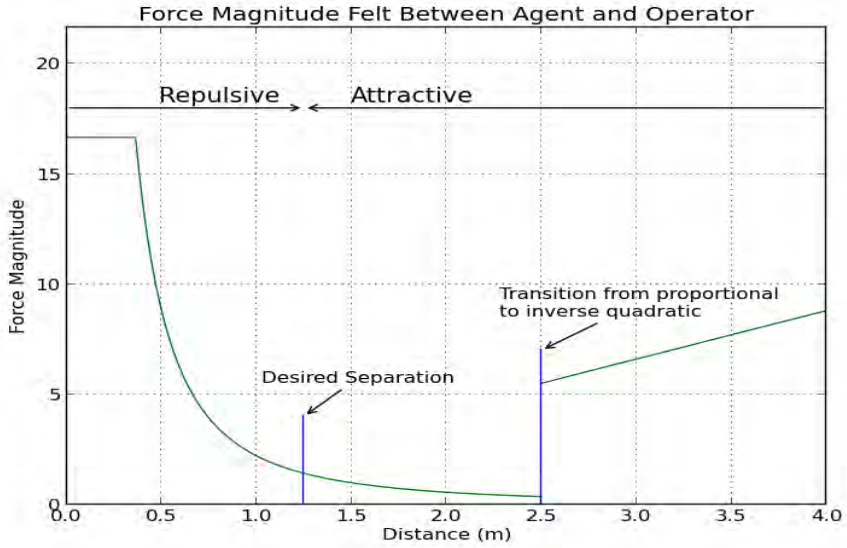
Adding an Operator



After many Δt but not too many Δt

$$\mathbf{F_{operator}} = \frac{CM}{(d_{m,op})^p}\hat{\mathbf{r}}_{\mathbf{m,op}} \qquad \text{where} \qquad d_{m,op} < 2d_{desired}$$

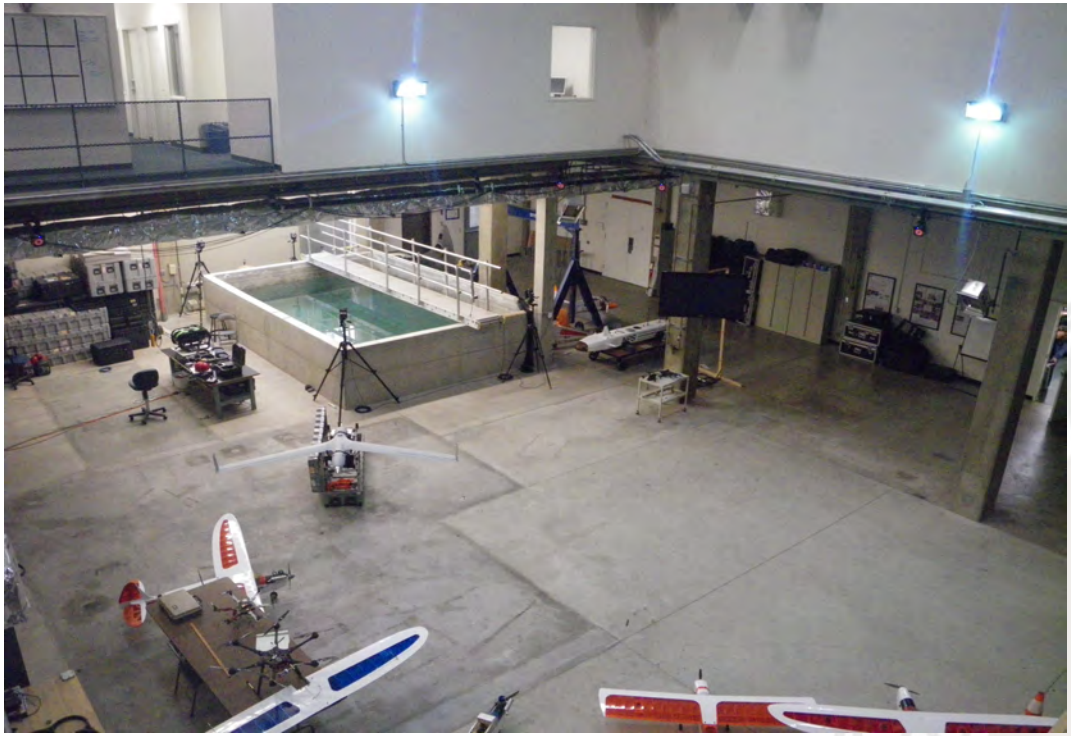
$$\mathbf{F_{operator}} = -CMd_{m,op}\hat{\mathbf{r}}_{\mathbf{m,op}} \qquad \text{where} \qquad d_{m,op} \geq 2d_{desired}$$



Test Platform

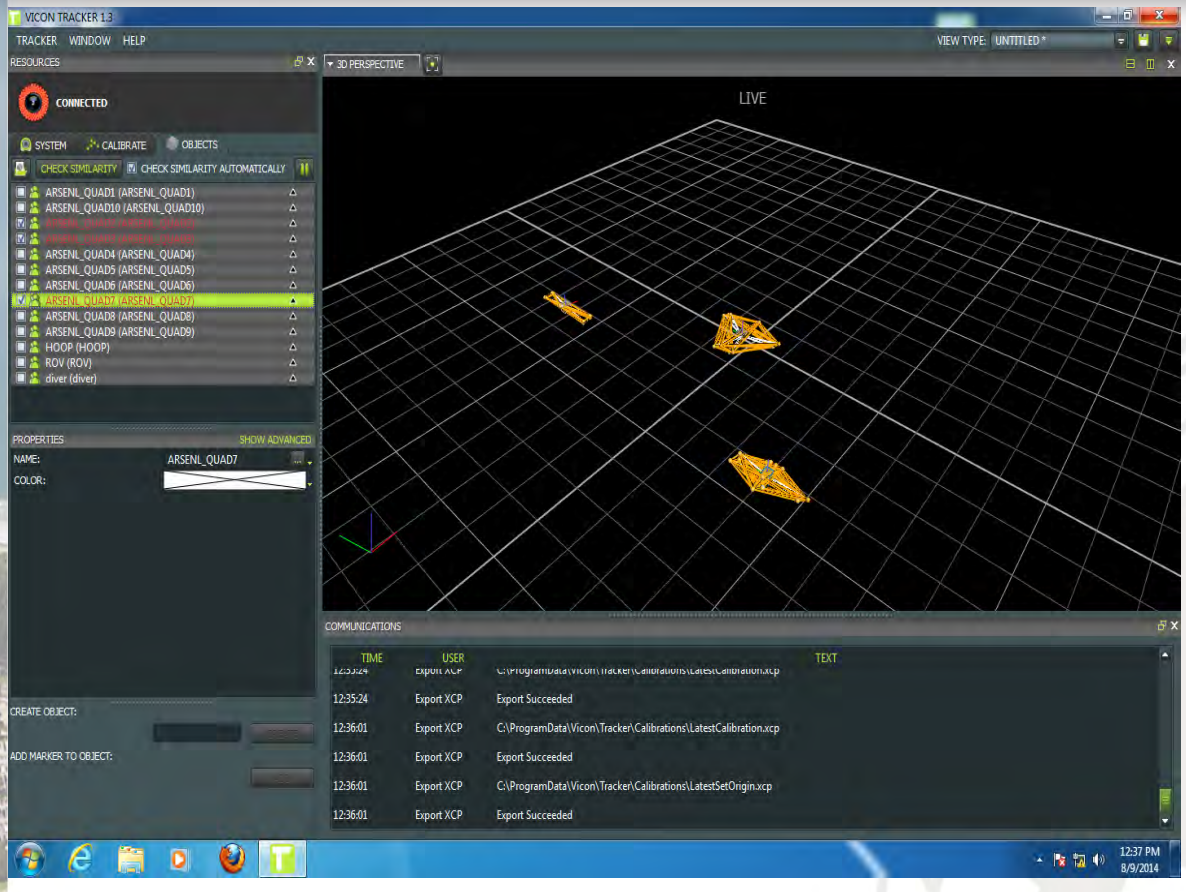
- Parrot AR.Drone™
  - 802.11b/g wifi self generated hotspot
  - 12 minutes of flight
  - Two cameras
  - Six Degrees of Freedom
  - Miniaturized IMUs track pitch, roll, and yaw
- Large open source base

Motion Capture

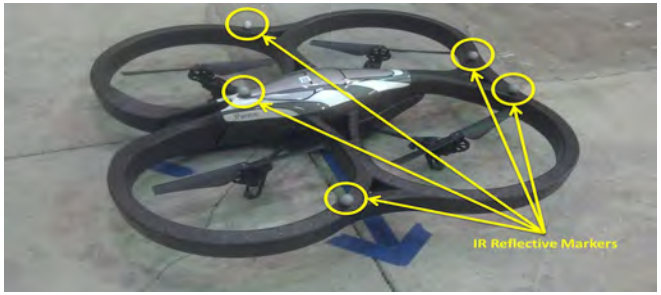


- VICON™
- 10 Cameras (and growing)
- Sub 1 cm accuracy
- x,y,z position and pitch,roll, yaw orientation

Constellation Identification and Tracking

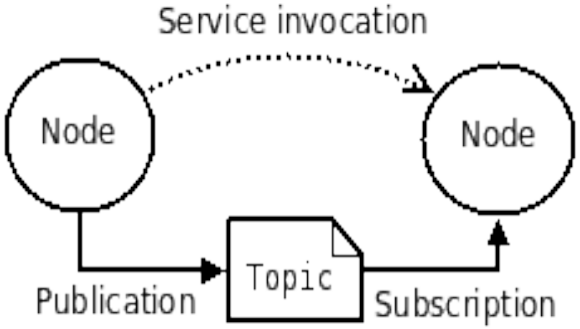


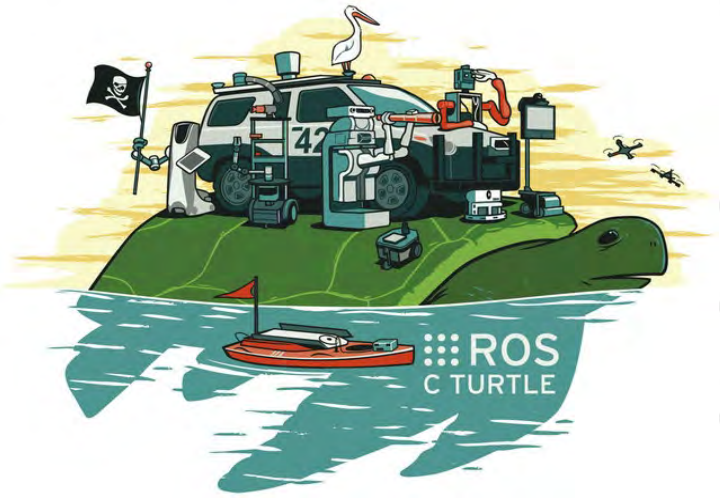
- IR reflectors, or markers, glued to objects
- Each object has a unique constellation
- Quaternions used to track orientation



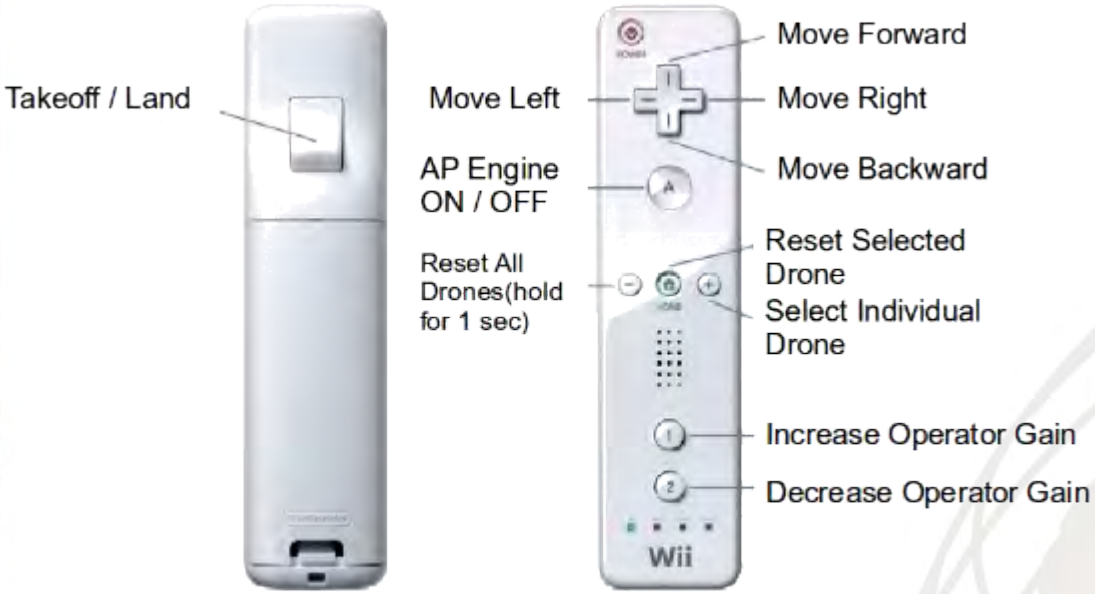
Robotic Operating System

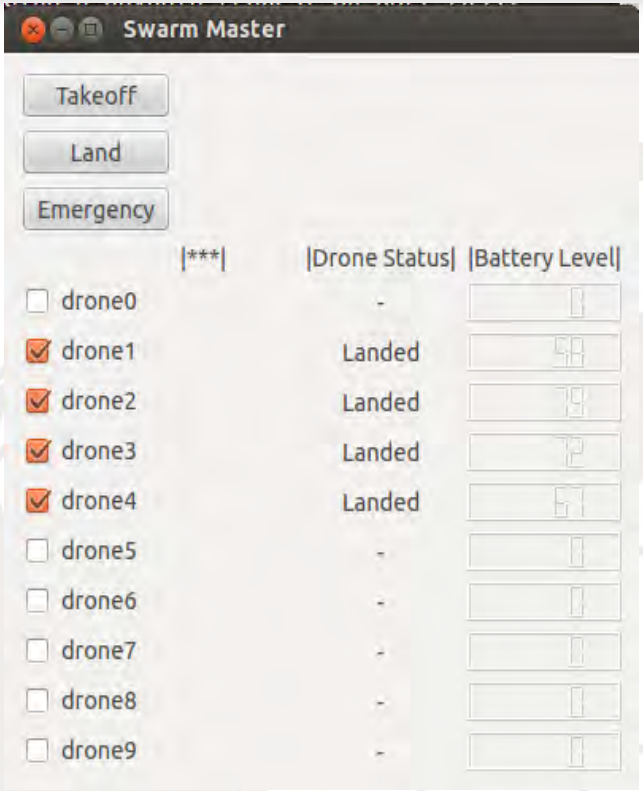
- Robotics Middleware
  - Hardware abstraction
  - Low-level device control
  - Implementation of commonly used functionality
  - Message-passing between processes
  - Package management
- Packages available for commonly available research and hobby grade sensors, controllers, and platforms
- Open Source





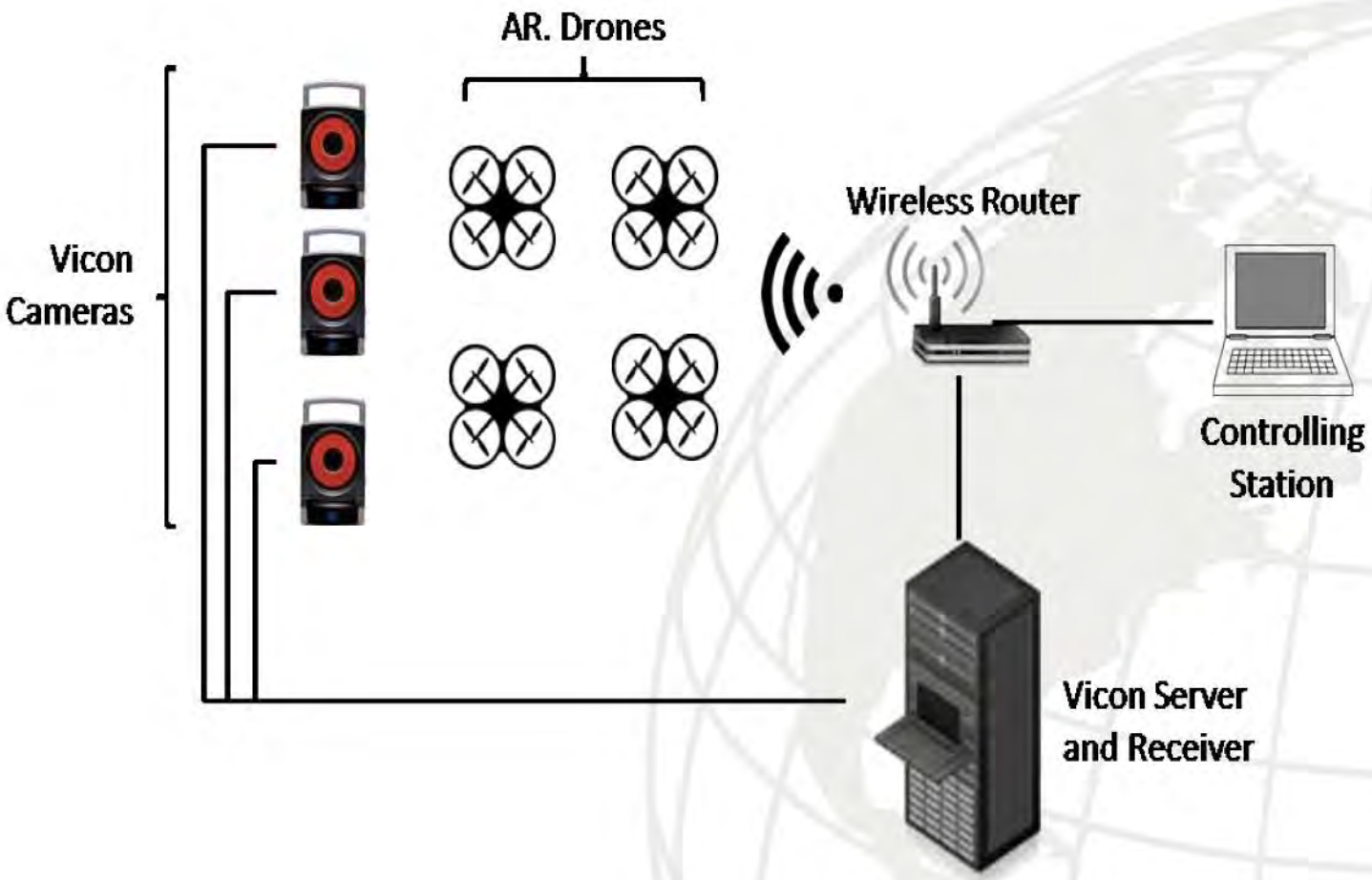
User Interfaces



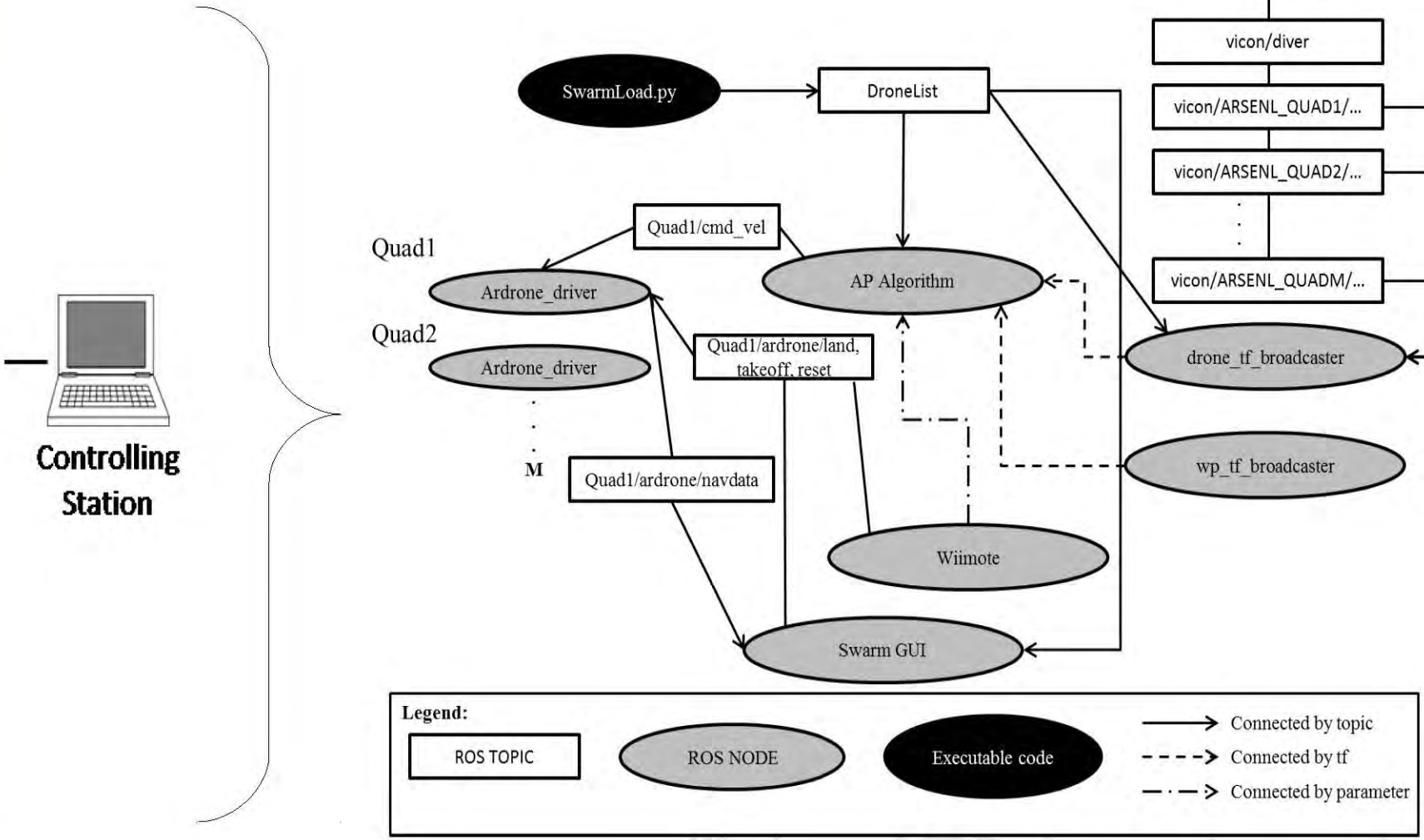


- Hand-held controller, Nintendo Wiimote, used for takeoff, landing, reset, parameter adjustment, and AP engine control
- Graphical User Interface used for group or single drone takeoff, landing, reset, and monitoring

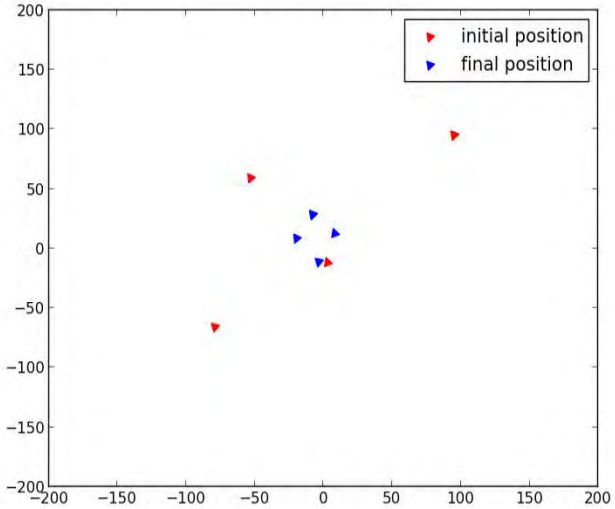
Hardware Integration

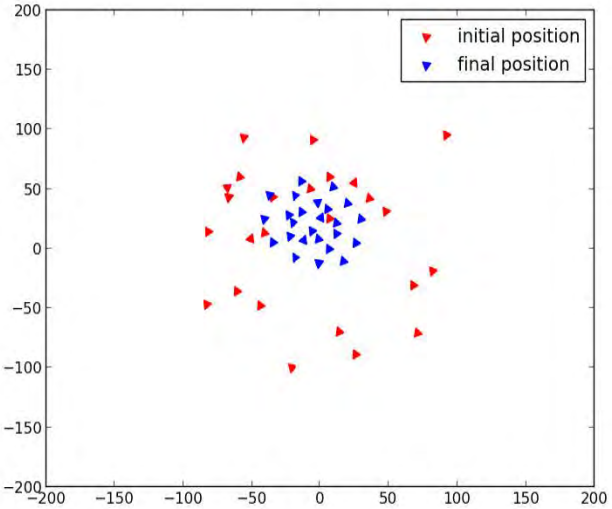


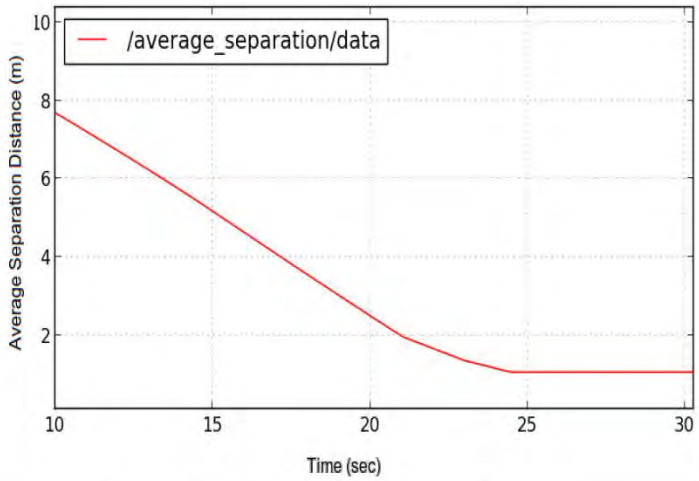
Software Integration



Simulation Results

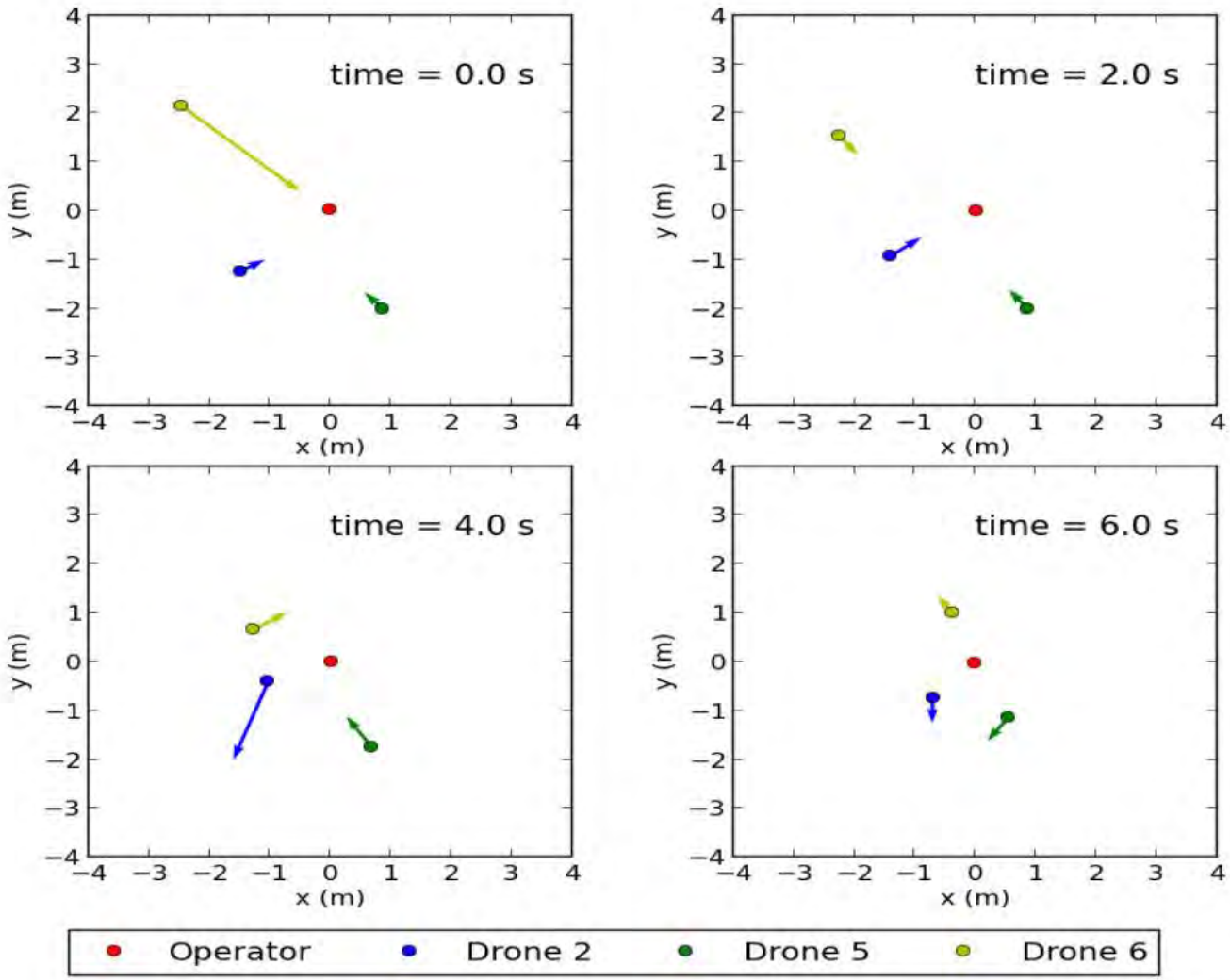




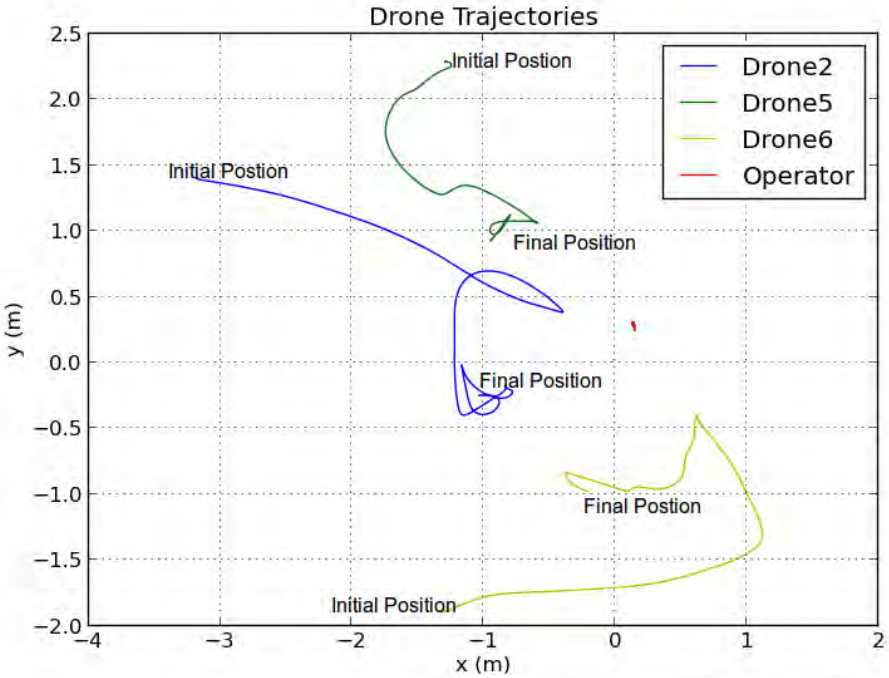


Physical Experimentation

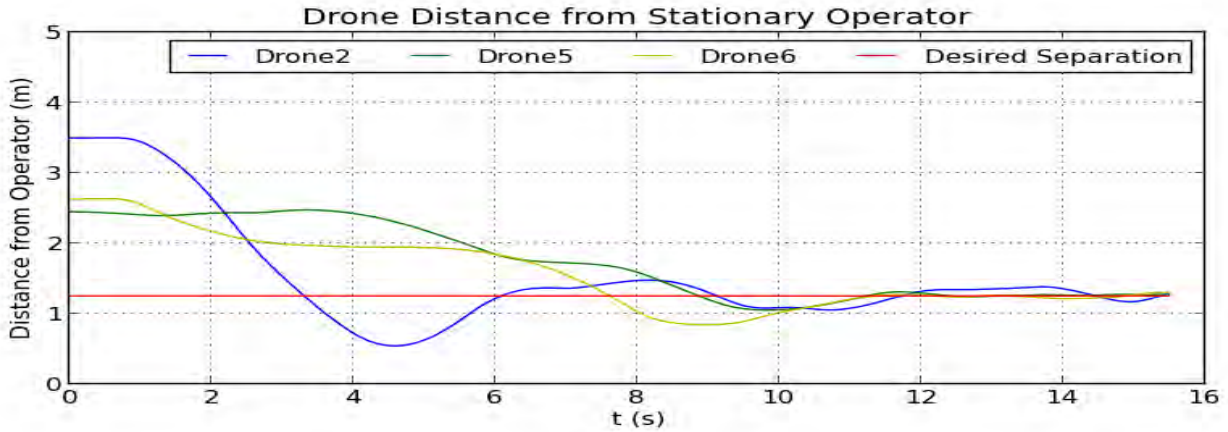
Force Vector Evolution



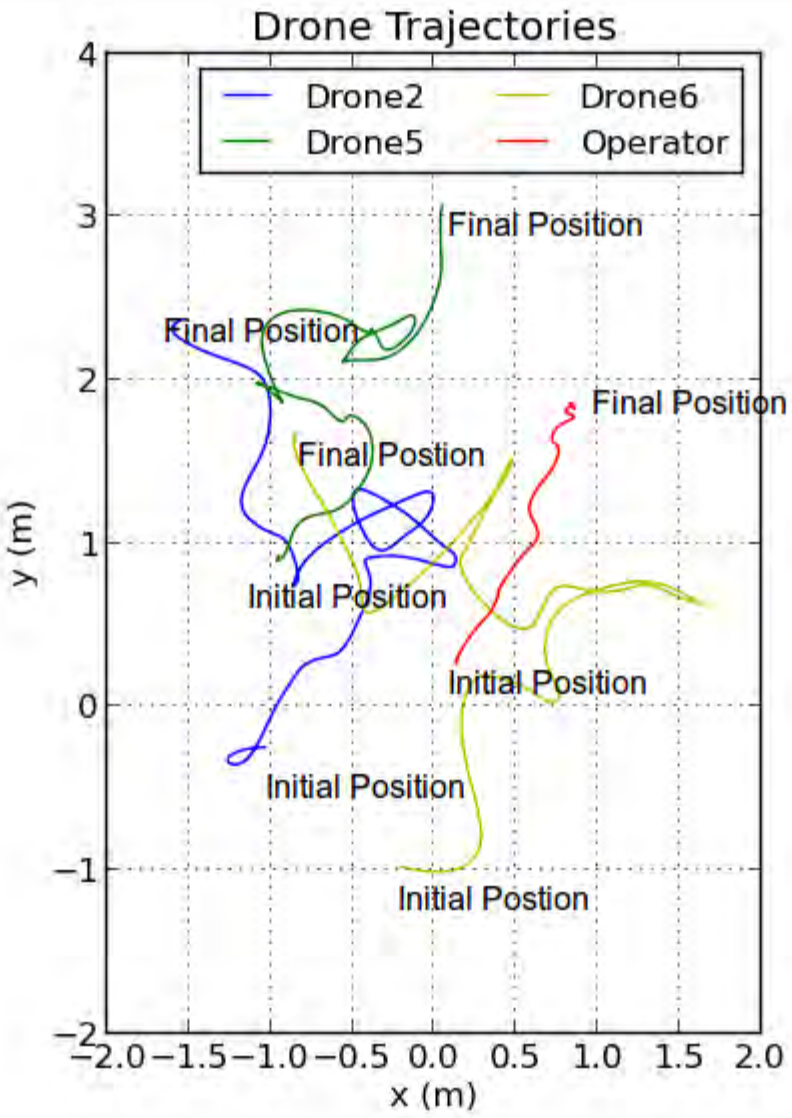
Stationary Operator



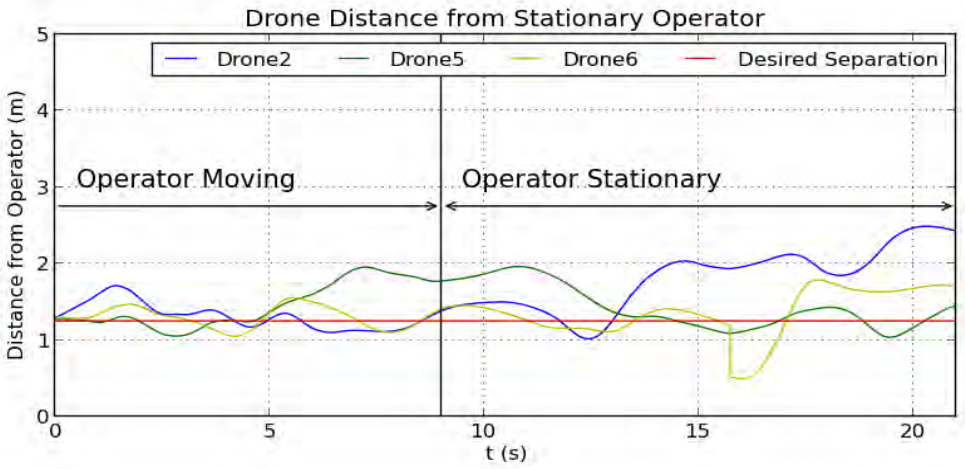
- After ~10 sec drones achieve tight formation around operator
- Stable formation with low separation error (< 20%)



Moving Operator



- Drones follow operator during movement
- Difficulty in recreating formation after operator stops



RVIZ Playback

Conclusion

- Demonstrated that an AP based framework allows a group of UAVs to autonomously follow a human operator
  - 2D and 3D simulations
  - Drone communication
  - Interface development: GUI and Wiimote
  - Hardware and software integration
  - Flight data playback
- Future work
  - Outdoor flight
  - More agent
  - Threat detection
  - Mission based testing

Questions?

References

- W. Spears, D. Spears, J. Hamann, and R. Heil, “Distributed, physics-based control of swarms of vehicles,” Autonomous Robots, pp. 137–162, 2004. [Online]. Available: http://link.springer.com/article/10.1023/B:AURO.0000033970.96785.f2
- M. Quigley, K. Conley, B. Gerkey, J. Faust, T. Foote, J. Leibs, R. Wheeler, and A. Y. Ng, “Ros: an open-source robot operating system,” in ICRA workshop on open source software, vol. 3, no. 3.2, 2009.
- Y. Koren and J. Borenstein, “Potential field methods and their inherent limitations for mobile robot navigation,” in Robotics and Automation, Proceedings., 1991 IEEE International Conference on. IEEE, 1991, pp. 1398–1404.
- L. Alboul, J. Saez-Pons, and J. Penders, “Mixed human-robot team navigation in the GUARDIANS project,” in 2008 IEEE International Workshop on Safety, Security and Rescue Robotics. IEEE, Oct. 2008, pp. 95–101. [Online]. Available: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4745884